STATE OF WYOMING

GAME AND FISH COMMISSION

GREEN RIVER FISH BARRIER DAM HYDRAULIC MODEL STUDY

CIVIL ENGINEERING DEPARTMENT

Engineering Research Center
Colorado State University
Fort Collins, Colorado

Prepared for
Fermelia and Johnson
Rock Springs, Wyoming

July 1967

CER67-68JFR-3

FINAL REPORT

OF

HYDRAULIC MODEL STUDY

OF

GREEN RIVER FISH BARRIER DAM

STATE OF WYOMING
GAME AND FISH COMMISSION
CHEYENNE, WYOMING

Prepared for
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by

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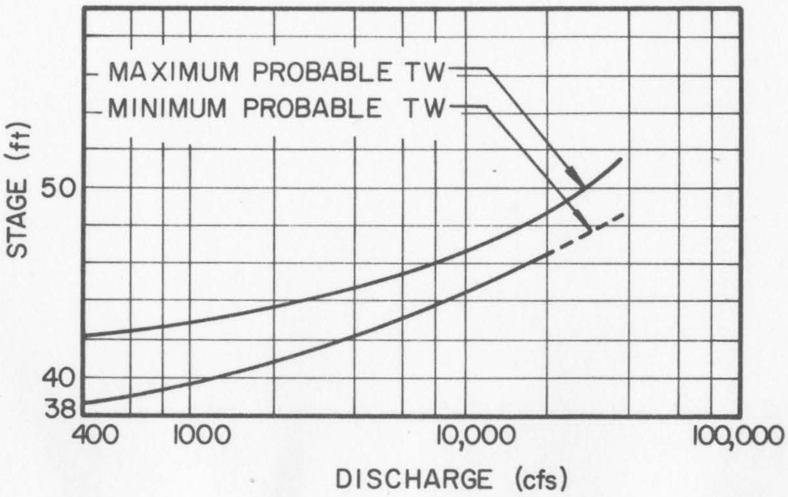

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PREFACE

The Engineering Research Center at Colorado State University is located between Horsetooth Reservoir of the Colorado Big Thompson Project and College Lake. The laboratories of the Center were strategically placed to utilize the high head, 250 ft., available from the reservoir and the storage capacity of the lakes. The Center is the focal point for research and graduate education.

There are five principal parts to the Center: the offices for staff and graduate students, the hydraulics laboratory, the fluid dynamics laboratory, the hydromechanical laboratory and the outdoor hydraulics-hydrology laboratory. The research activities of the Center are in fluid mechanics, hydraulics, hydrology, ground-water, soil mechanics, hydro-biology, geomorphology and environmental engineering.

The hydraulics laboratory includes 50, 000 square feet of floor space in which basic and applied research activities are undertaken. The floor of the laboratory is constructed over a large sump system, having one acre-foot capacity, which permits recirculation of water through the various research facilities. Generally, pumps are used for recirculation but the high head and large flow capacity from the reservoir can also be utilized.

The Center includes well equipped machine and woodwork shops. All research facilities of the Center are constructed on site and in the case of this model study, necessary metal work and carpentry were done by personnel in the shops. The shop personnel are particularly well experienced in the art and skill of model construction.

This model study was undertaken by Colorado State University in close coordination with Fermelia and Johnson of Rock Springs, Wyoming, for whom this work was done. The urgent need of hydraulic information for purposes of planning and design was recognized from the beginning and all information obtained from the model studies relevant to those purposes were transmitted in advance of this report. Decisions affecting model construction tests or testing program, or time schedules were made with mutual consent through assessment of appropriate information and consideration and accord with project planning.

Grateful acknowledgment is hereby expressed by the writer to personnel at Fermelia and Johnson for their cooperation, to personnel of the shops for their ingenious contributions in solving model construction problems, particularly in the metal works, and to others contributing to the model study and the preparation of this report.

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SUMMARY

This report describes the hydraulic model study of the spillway and boundary adjacent to the fish trap for a proposed Green River fish barrier dam. Pressures and flow distribution were studied. Also described are the tests performed to determine the head loss coefficients for screens to be installed in the fish traps. The approach velocities and heads upstream and downstream from the screens were measured in this study.

The spillway, as designed, performed satisfactorily for a range of discharges representing the prototype conditions. The spillway also operated satisfactorily at discharges greater than anticipated in the prototype. The spillway was modified by reducing the apron length 12 ft. for economical reasons and continued to perform as expected. A discharge rating curve for the spillway is given in Fig. 7. A cursory study of the spillway with the axis skewed indicated little effect on the performance of the spillway with a skew angle of 10^0.

The wing walls downstream from the fish trap were modified to eliminate the formation of an eddy near the bank. Flow lines were always outward from the downstream collection gallery thus providing an attraction current for the migrating fish.

Graded riprap of 15-in. maximum size should be provided in a layer 2 ft. thick for a distance of 50 ft. downstream from the end sill. A gravel or reverse filter layer should underlie the riprap. The riprap should extend up the banks and be placed in the transition from the fish trap to the river channel.

The head losses across the screens were determined for approach velocities as great as 7 fps. The loss coefficients, K , for different screens are given in Table III.

The chapters of this report describe the construction of the model and screen testing facilities, the tests performed, and give the conclusions and recommendations. The data collected is presented in the appendices.

Chapter I

INTRODUCTION

General Description and Concept of Project

The Green River Fish Barrier Dam, proposed for construction, is the major feature of a system to prevent the movement of and to possibly eliminate "rough" fish from the section of the Green River above the dam. The dam, in conjunction with the fish trap, will eliminate the need to poison the entire fish population of the river every three or four years.

The dam site is located approximately two miles southeast of La Barge in Southwestern Wyoming. The barrier dam, shown in Fig. 1, consists of a weir with an ogee crest and a downward sloping apron terminating in a wedge-shaped end sill. The crest length is 153 feet. A bridge may be required for access to the trap, thereby requiring the four piers supported by the dam. The spillway design flood is 15,000 cfs.

The fish trap, also shown in Fig. 1, is located at the right[1] abutment. Fish moving downstream encounter screens on the crest of the dam and move laterally to the collection gallery. They then pass through one of three gates where they are intercepted by an obliquely angled screen and are directed to the trap. Fish moving upstream encounter one of two collection galleries. These are the spillway gallery and the channel gallery. From here they move upstream following the current until they encounter a screen and are directed into the trap.

Scope of the Study

The purpose of the study was to evaluate the hydraulic characteristics of flow over the spillway and through the fish traps, and to study the fish screens proposed for the traps. To accomplish these objectives, the study was divided into two parts. The first part consisted of a model study to evaluate the spillway and fish trap boundary. The second part involved screens with prototype dimensions and velocities.

The specific objectives of the model study are listed below:

1. Determine the discharge coefficient and establish a discharge rating curve for the spillway.

2. Measure pressures at the boundary of the spillway.

3. Determine water surface profiles at the spillway.

4. Verify outward velocities from collection gallery and channel collection gallery ports.

5. Optimize the stilling basin.

6. Determine location of probable maximum scour and riprap requirements.

The specific objectives of the screen study are listed below:

1. Determine the loss coefficients of the screens for different center to center bar spacings.

2. Determine the effect on the loss coefficients caused by tilting the screens into the approaching flow.

Model Criteria

The objective of the model study is to predict prototype behavior. For purposes of this study, the inertial and gravitational forces predominate. The Froude criterion was selected to determine the geometric scale.

The distribution and pattern of flow in the vicinity of the fish trap and collection galleries were most important. Therefore, it was decided to model only half of the spillway and use a model scale as large as practical. Even with the scale ratio finally chosen, this meant qualitative and not quantitative data for the interior of the fish traps. To study the trap interior would require an even larger model and another study if quantitative information was desired.

A model-prototype relationship of 1:25 was selected based upon a model size that would give an accurate representation of the flow conditions. A list of some characteristic model-prototype ratios based upon the selected scale is given in Table I.

[1] Left and right as used in this report refer to the left and right of an observer looking downstream.

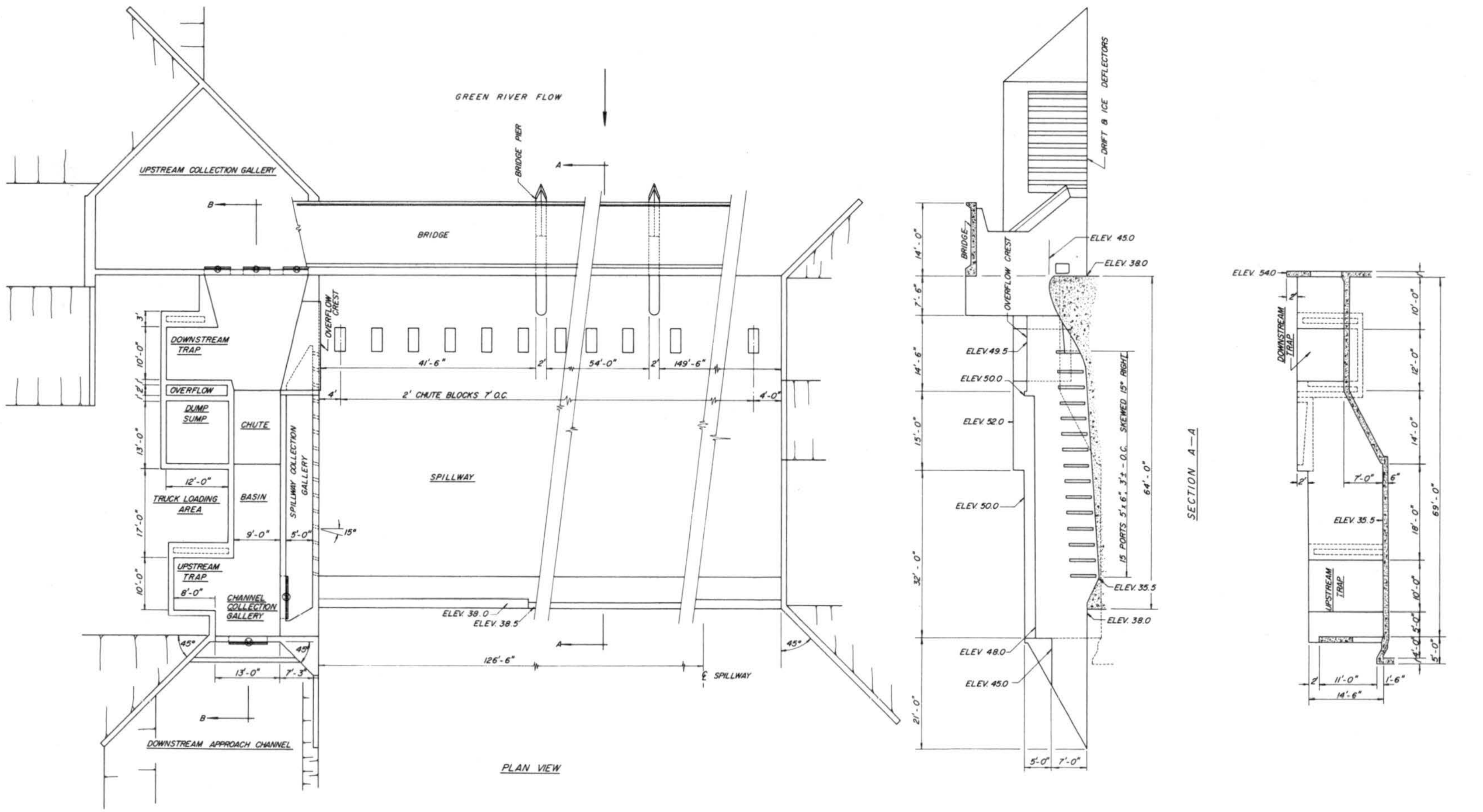


FIGURE I DETAILS OF BARRIER DAM

TABLE I

MODEL PROTOTYPE SCALE RATIOS

Parameter	Scale Ratio		Absolute Magnitude	
	Function of the length	Numerical ratio	Prototype	Model
Length	L_r	1:25	25 ft	1 ft
Area	L_r^2	1:625	625 ft^2	1 ft^2
Velocity	$L_r^{1/2}$	1:5	5 fps	1 fps
Discharge	$L_r^{5/2}$	1:3125	3125 cfs	1 cfs
Time	$L_r^{1/2}$	1:5	5 min	1 min

Chapter II

THE MODEL AND FISH SCREENS

Model Construction

Dimensions of the model facilities and the arrangement are given in Fig. 2. A photograph of the complete model is shown in Fig. 3. Only a significant segment of the river channel in the vicinity of the proposed dam was included in this model. The model was constructed as a mirror image of the prototype. This requirement was necessary to use an existing headbox. The model was constructed primarily with plywood. Sheet metal was molded over a wooden frame to form the crest and apron of the spillway. All wood sections were painted with fiberglass to provide a waterproof seal. The sheet metal was painted, sanded, and waxed to achieve as smooth finish as possible. Sand was used to model the river bed and banks.

Water was supplied to the model by a 14-in. turbine pump. The discharge was regulated by a valve in the supply line. A rock baffle was used to distribute the flow uniformly across the approach channel to the dam. The discharge measurements were made with a calibrated orifice in the supply line.

Piezometers were installed in the spillway at the locations shown in Fig. 4. All piezometers were attached to manometer boards with flexible polyethylene tubing.

Screen Construction

Two steel frames were constructed with dimensions shown in Fig. 5. The frames were drilled with 17/32-in. holes located at 3/4-in. center to center spacings. Bars 1/2-in. in diameter were then positioned in the frames. With all the bars in position or by removing every other bar, screens with clear spacings between bars of 1/4 in., 1/2 in., 1 in. and 1 1/2 in. could be easily fabricated.

The screens were then positioned in a constricted segment of an 8 ft. wide flume as shown in Fig. 6. The measurements of the water surface were made with point gages located at the positions shown in Fig. 6. Discharge measurements were made with a calibrated orifice in the supply line. Velocity measurements were made with a Price current meter at the same location as the upstream point gage.

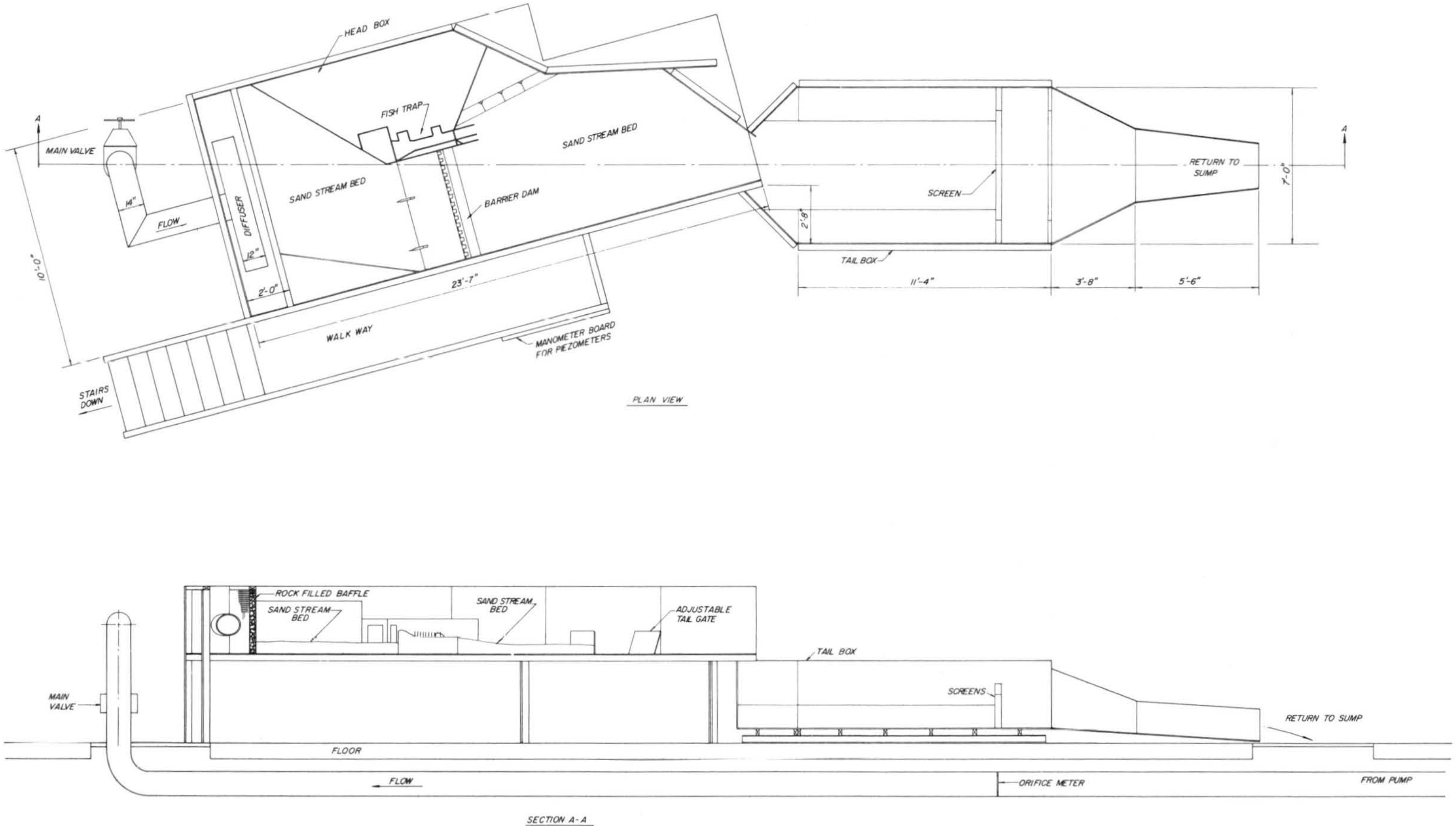


FIGURE 2 SCHEMATIC DRAWING OF THE MODEL

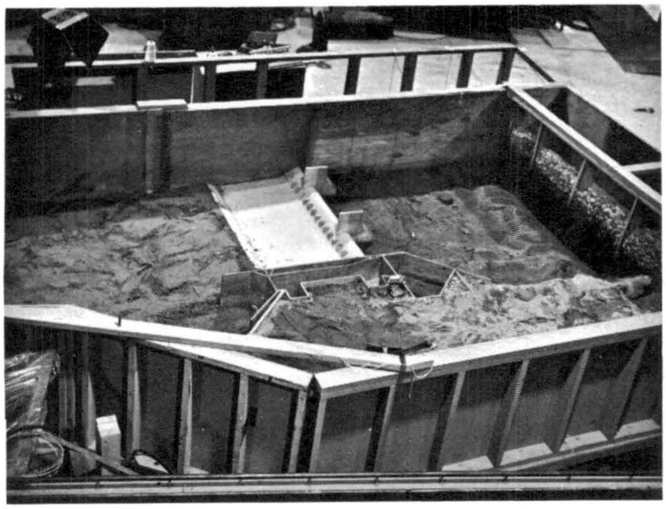
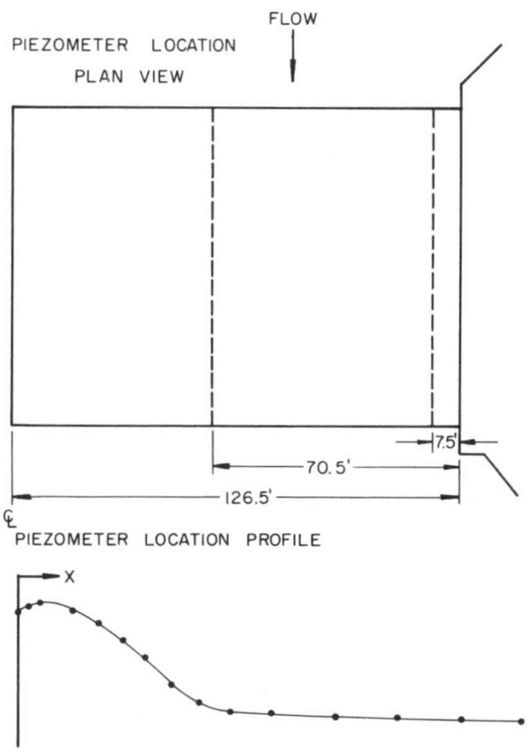


Figure 3. Photograph of model



Profile

Piez. No.	X ft	Elev. ft
A&B 1	0	44.33
2	0.77	44.90
3	1.63	45.00
4	3.94	44.50
5	4.98	44.00
6	6.52	43.00
7	7.73	42.00
8	8.73	41.00
9	9.58	38.75
10	15.62	37.70
11	20.62	37.50
12	30.02	37.00
13	39.41	36.50
14	48.80	36.00
15	58.20	35.50

Figure 4. Spillway piezometer locations

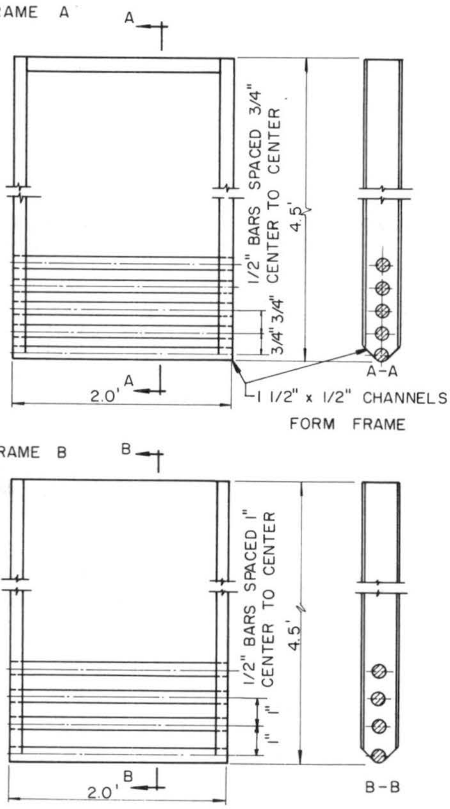


Figure 5. Details of the fish screens

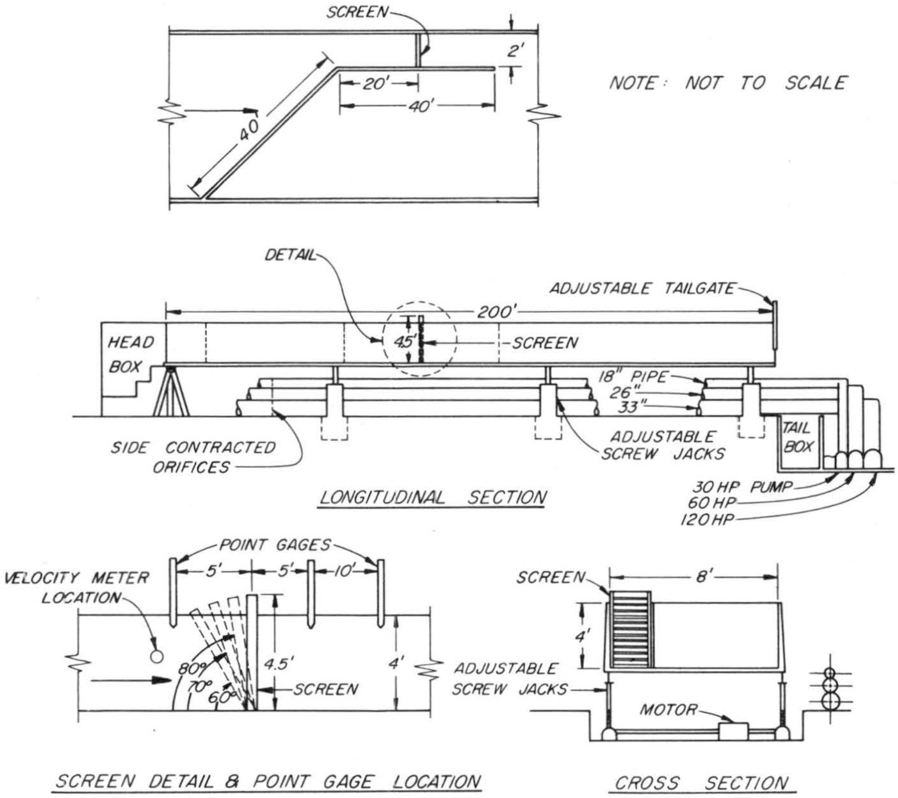


Figure 6. Schematic drawing of fish screen testing facility

Chapter III

TESTS AND RESULTS

Model Tests

The model test program was designed to provide sufficient information to predict prototype behavior for a wide range of discharges. Pressures on the spillway boundary were measured and recorded for discharges up to 26, 200 cfs. Surface flow distributions were recorded photographically. Flow distributions within the fish trap were visually observed by injecting dye into the water. Observations within the trap were qualitative only.

The Main Spillway

Pressure - In the first series of test runs, the fish trap intake gates were closed and all flow passed over the main spillway. Pressures on the surface of the crest and apron were measured and are given in Table 1 of Appendix A.

Pressures were satisfactorily positive at all piezometer locations (see Fig. 4 for piezometer locations) for discharges less than about 16, 000 cfs. Negative pressures were recorded for piezometer A3, A4, B3 and B4 for discharges greater than 16, 000 cfs. The minimum pressure recorded was -1.7 ft. of water at piezometer A3 for a discharge of 26, 200 cfs. The pressure was not considered excessive or to be cause for concern. Pressures greater than -10 ft. of water were considered to be satisfactory. The -10 ft. of water is a safety factor to insure that cavitation will not occur and cause damage to the structure and is based upon a rule of thumb from previous model studies and prototype results.

In the second series of test runs, the fish trap intake gates were opened and a series of discharges were again passed through the spillway. Pressure data for this series of runs are given in Table II of Appendix A. Essentially, the same order of magnitude of pressures were recorded for these runs as were previously recorded for the runs with the intake gates closed.

Rating curve - The model spillway rating curve is given in Fig. 7. The curve shown here is for the conditions when the fish trap intake gates are closed and all the flow is passing over the main spillway. No attempt was made to rate the amount of discharge passing through the trap since in the prototype the discharge will be regulated by the intake gates.

Stilling basin - The stilling basin was tested for discharges as great as 26, 200 cfs and for conditions of different tailwater. The maximum and minimum tailwater rating curves for the river reach at the dam site are given in Fig. 8.

The basin performed satisfactorily within the limits of the tailwater rating curves for all discharges. Figs. 9a and 9b show the basin operation at discharges of 6, 000 cfs and 14, 000 cfs with minimum tailwater conditions.

After observing the operation of the stilling basin, modifications were suggested. These modifications were not required to improve the basin performance since it was satisfactory, but were designed to realize some economical benefits in the construction of the prototype structure. The modifications and subsequent tests are described in the following paragraphs.

The first modification involved shortening the basin apron by 10 ft. This was accomplished by moving the original end sill upstream. The basin performed satisfactorily for these conditions as seen in Figs. 10a and 10b which illustrate minimum tailwater conditions.

The chute blocks did not appear to have much effect on the hydraulic jump for maximum tailwater conditions. For minimum tailwater settings the chute blocks did appear to stabilize the toe of the jump. However, if they could be removed and not significantly effect the basin performance, a substantial savings could be realized. Therefore, the next modification to the basin was the removal of the chute blocks.

The basin continued to operate satisfactorily without the chute blocks. For maximum tailwater, no significant difference in the hydraulic jump characteristics could be determined at any discharge less than and including 15, 000 cfs. A discharge of 15, 000 cfs was the maximum tested for the above conditions. For conditions of minimum tailwater, two effects were noted. First, the jump formed 2 to 4 ft. farther downstream. Secondly, the front or toe of the hydraulic jump appeared more oscillatory about its new position as shown in Figs. 11a and 11b. Neither of these effects were detrimental to the structure or cause for concern. In fact, moving the jump downstream reduced the chances of fish being able to proceed upstream over the crest.

At this point, further reduction of the apron length appeared feasible. The end sill was moved an additional 2 ft. upstream for a total apron length reduction of 12 ft. Tests were again performed for discharge up to a maximum of 15, 000 cfs. The stilling basin performance remained satisfactory and is shown in Figs. 12a and 12b. No significant differences could be distinguished between the hydraulic jumps or downstream water surfaces

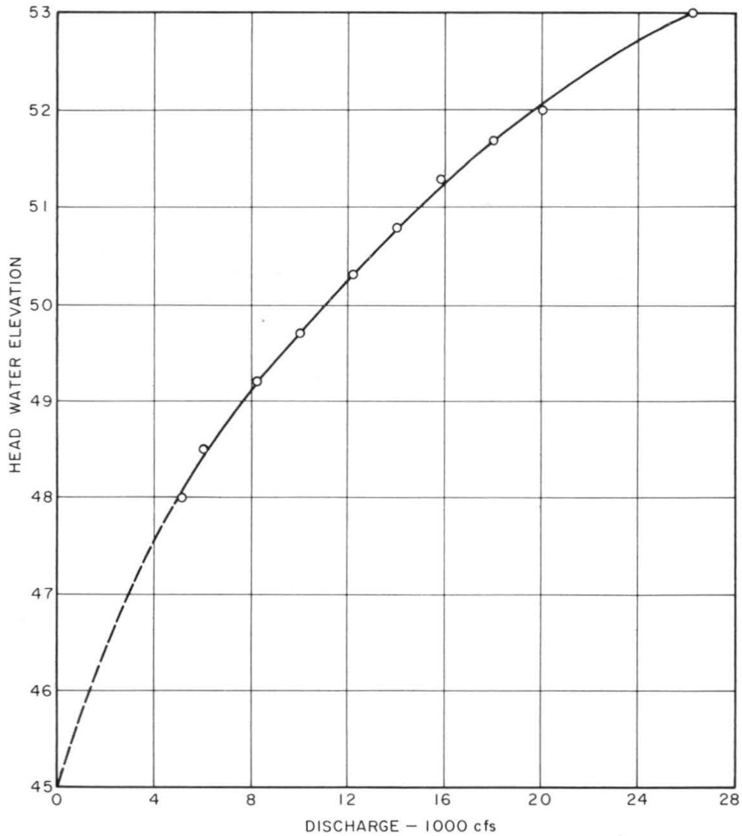


Figure 7. Model spillway discharge rating curve

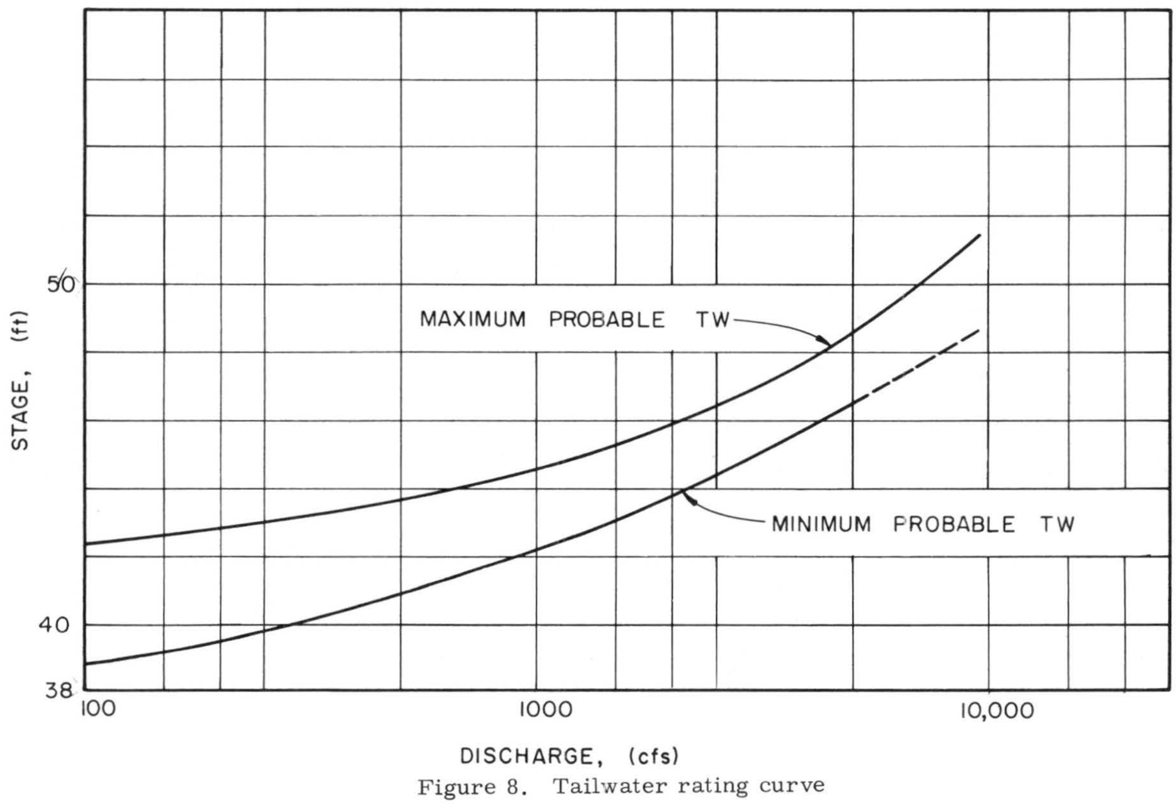


Figure 8. Tailwater rating curve

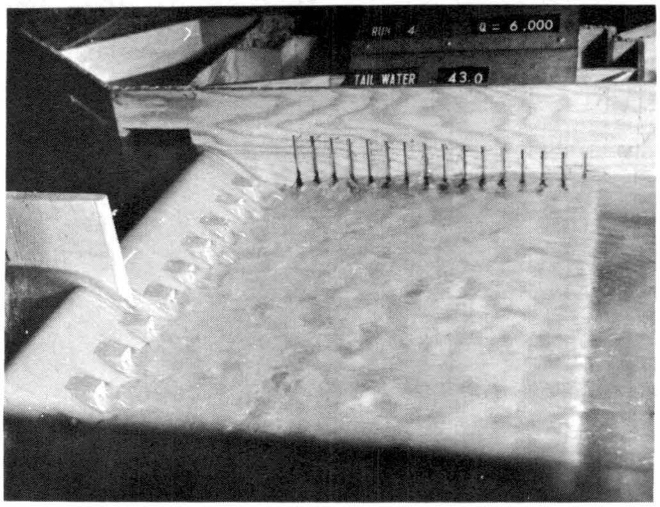


Figure 9a. Photograph of stilling basin, Q = 6,000 cfs, tailwater elevation = 43.8

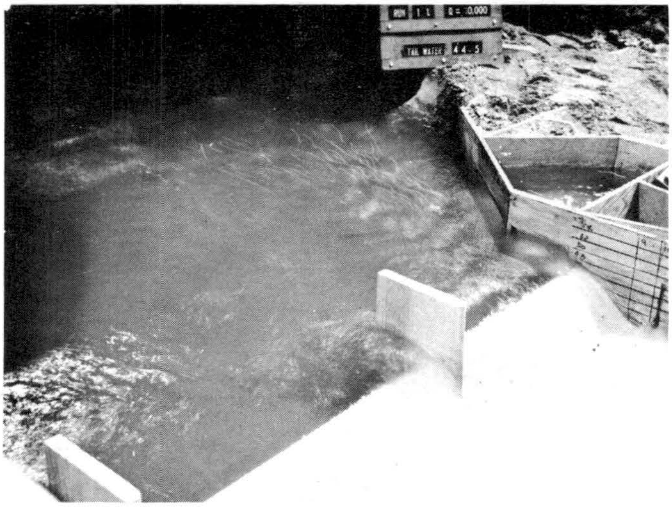


Figure 9b. Photograph of stilling basin, Q = 10,000 cfs, tailwater elevation = 45.8

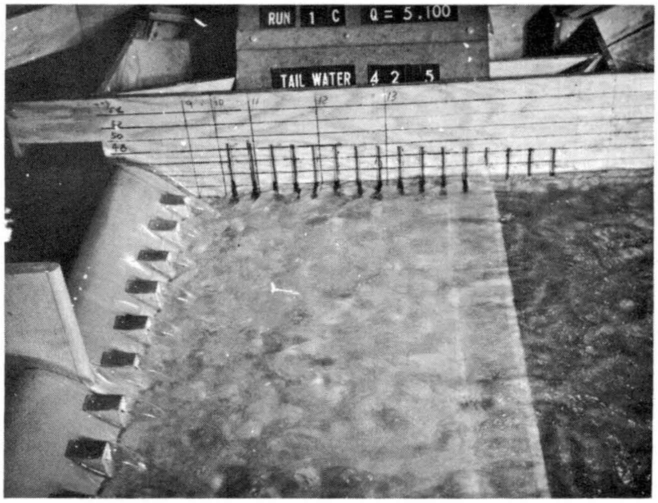


Figure 10a. Photograph of modified stilling basin (apron length reduced 10 ft.), Q= 5,100 cfs, tailwater elevation = 42.5

Figure 10b. Photograph of modified stilling basin (apron length reduced 10 ft.), Q= 15,000 cfs, tailwater elevation = 45.5

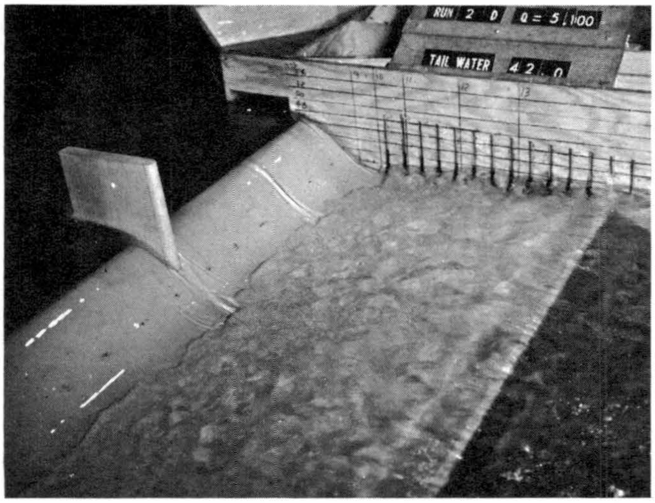


Figure 11a. Photograph of modified stilling basin (apron length reduced 10 ft. and chute blocks removed), Q = 5, 100 cfs, tail-water elevation = 42. 0

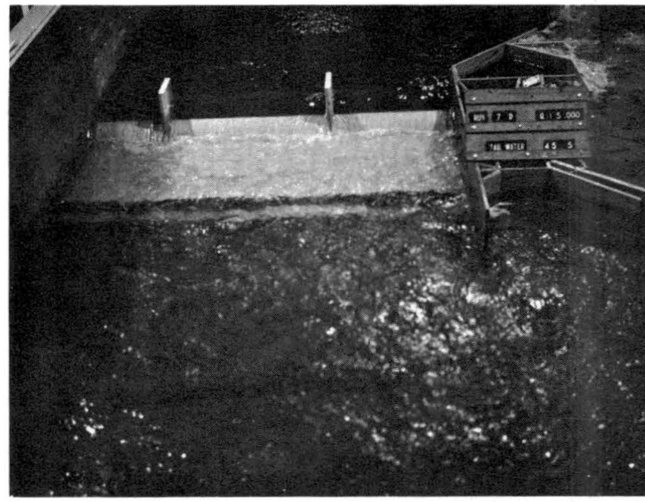


Figure 11b. Photograph of modified stilling basin (apron length reduced 10 ft. and chute blocks removed), Q = 15, 000 cfs, tail-water elevation = 45. 5

Figure 12a. Photograph of modified stilling basin (apron length reduced 12 ft. and chute blocks removed), Q = 5, 100 cfs, tail-water elevation = 42. 5

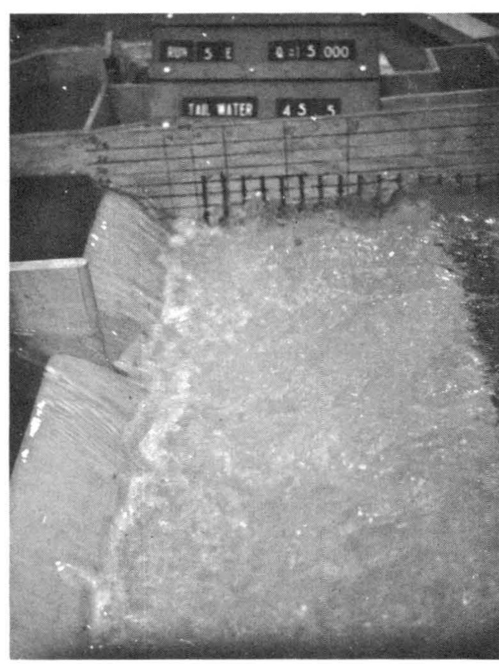


Figure 12b. Photograph of modified stilling basin (apron length reduced 12 ft. and chute blocks removed), Q = 15, 000 cfs, tail-water elevation = 45. 5

when the basin was shortened 10 ft. or 12 ft.

End sill - Two dentated end sills were tested in addition to the solid end sill. Fig. 13 shows the details of all three of the end sills. The purpose of testing the dentated sills was to see if end sills with smaller volumes of concrete would perform satisfactorily. The tests performed with the various end sills installed included operating the model at maximum and minimum tailwater and then reducing the tailwater until the jump was swept off the apron. The sand channel downstream from the basin was also observed. The scouring of the channel is described hereinafter in the section entitled "Scour Control".

All three end sills, the solid and two dentated end sills, performed equally satisfactorily within the maximum and minimum tailwater limits for discharges of 5,100, 10,000 and 15,000 cfs which were tested. At 5,100 cfs the hydraulic jump could not be swept out of the basin by lowering the tailwater in any case. At 10,000 cfs the jump was swept out of the basin at a tailwater elevation of about 41.5 in every case. At 15,000 cfs the jump was swept out of basin at a tailwater elevation of 43.8 with the solid sill installed and at tailwater elevations of 43.0 and 43.5 for dentated end sills #1 and #2, respectively (refer to Fig. 13 for details of dentated end sills #1 and #2).

Water surface profiles - Figs. 14a and 14b show the water surface profile at the spillway for a discharge of 15,000 cfs and tailwater elevations of 47.0 and 49.3, respectively. The profile depicts the condition when the apron length has been reduced 12 ft. and the dentated end sill #1 is installed.

Axis of dam skewed - During the course of the testing program it was suggested by the consulting engineers that skewing the axis of the dam with respect to the channel might result in improved trapping efficiency. Therefore, an attempt was made to determine the effects on the hydraulic performance of the skewed spillway. This was a qualitative analysis and somewhat superficial due to limitations of the model head box.

The flow was forced to approach the spillway at angles of 10^0, 20^0 and 30^0 from a line normal to the axis of the spillway and on the side of the fish trap. The approaching flow patterns for a discharge of 10,000 cfs are shown in Figs. 15a, 15b and 15c for angles of 10^0, 20^0 and 30^0, respectively. The orientation of the piers with respect to the spillway axis was not changed in the model.

The most notable effect of the skewed axis was the local scour around the bridge piers. The water "piled up" on the downstream side of the pier and a considerable amount of turbulence was evident. The pile up of water was above the region of maximum scour. The depth of scour at the pier increased as the angle of attack increased. This was the only significant effect of skewing the dam and this should not necessarily be cause for concern since, in the prototype, the piers would be oriented in a direction parallel to the flow. This orientation would reduce the amount of local scour. The scour would then be comparable to the scour when the approaching flow was normal to the dam axis and this scour was negligible.

Another factor to consider when analyzing the dam with a skewed axis is the increased length of the crest. In the case of a skew angle of 30^0, the overall crest length would be about 177 ft. This is a 15.7% increase in the crest length over a dam that is not skewed.

The spillway discharge coefficient would deviate from that found for the dam with an axis perpendicular to the direction of flow. However, no attempt was made to check the coefficient or prepare a rating curve for the conditions when the skew angle was greater than 10^0. For a skew angle of 10^0 or less, no significant difference in the spillway rating curve from that given in Fig. 7 could be distinquished. Therefore, the rating curve given in Fig. 7 can also be used for a dam with the axis skewed at 10^0 if the crest length remains the same (153 ft.).

Consideration must be given to the effect on the main thalweg if the axis is skewed. The flow may tend to pile up along the bank near the downstream abutment. The thalweg would follow the crest and the stilling basin apron. Additional bank protection may be required on the region downstream from the skewed dam and should be considered in the final analysis.

The Fish Trap

General observations - Test runs were performed for a range of total discharge of 5,300 cfs to 15,400 cfs passing over the main spillway and through the fish traps. Visual observations were the primary source of data for the trap complex. Photographs of the surface streamlines in the vicinity of the trap intake were also taken. The following discussions are based upon qualitative data only. A larger scale model is required for quantitative data.

Water entering the trap complex passed through the upstream collection gallery. The pattern of surface streamlines entering and within the collection gallery are shown in Fig. 16. The flow enters the gallery smoothly and without any apparent disturbance to the flow in the main channel. A large eddy was evident to the left of the three trap intake ports and can be seen in Fig. 16. The eddy was observed in the region at all discharges. The eddy did not interfere with the hydraulic performance of the trap. However, it does have reduced velocities compared to the velocity in the main current and could become a resting area for fish migrating downstream. This eddy could be reduced or eliminated by moving the wall of the collection gallery. The new wall would be parallel to the

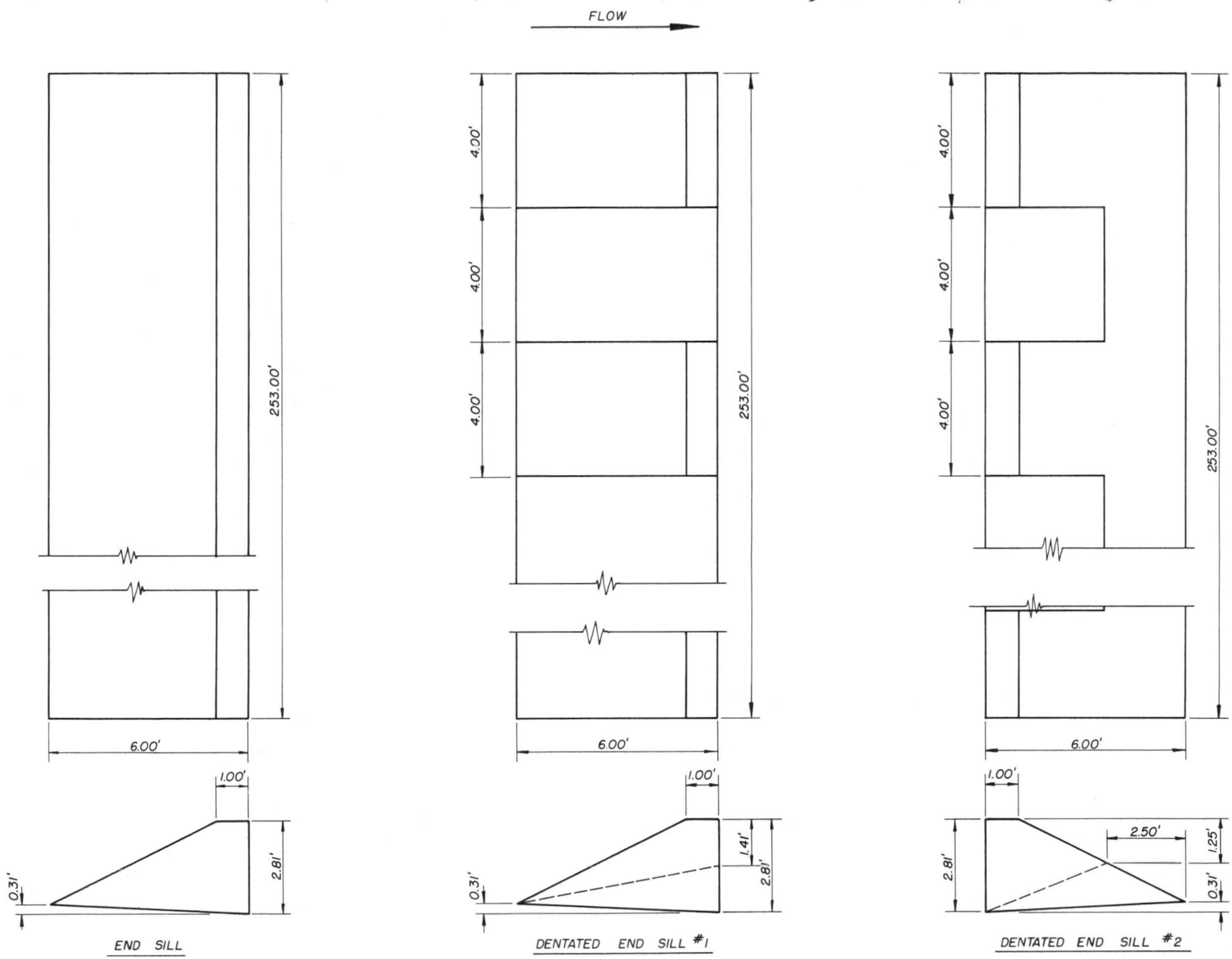


FIGURE 13 DETAILS OF END SILLS

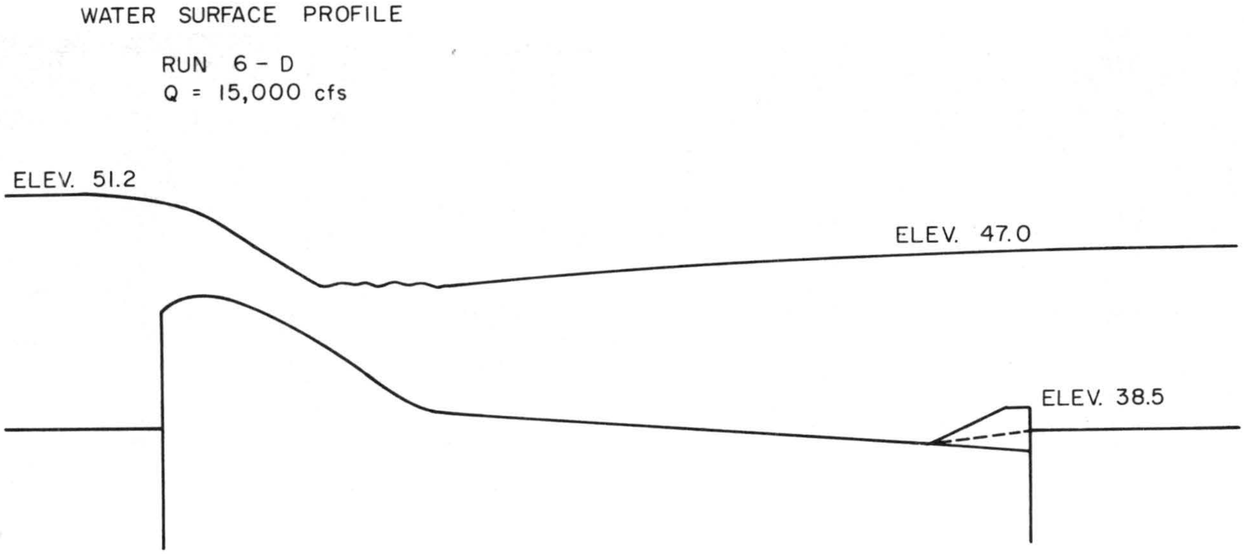


Figure 14a. Water surface profiles with dentated end sill # 1 on apron shortened 12 ft., Q = 15,000 cfs

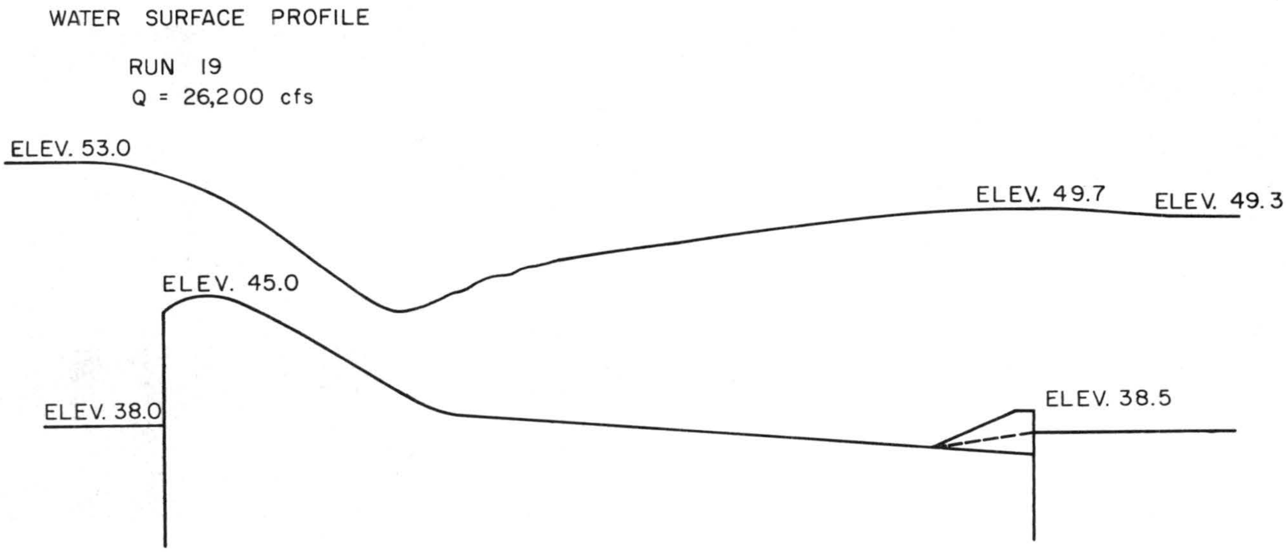


Figure 14b. Water surface profiles with dentated end sill # 1 on apron shortened 12 ft., Q = 26,200 cfs

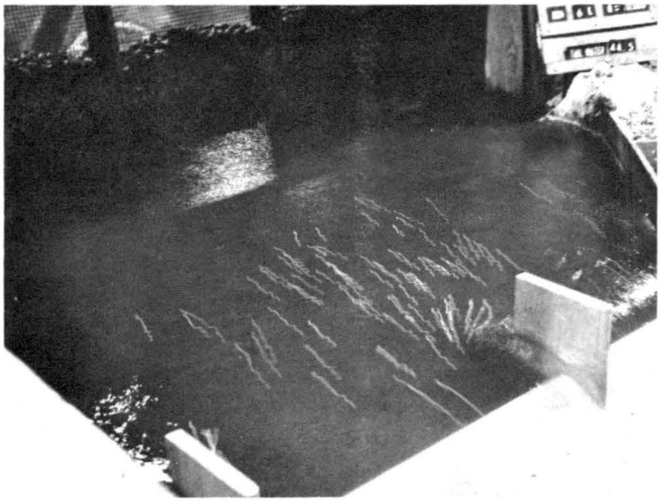


Figure 15a. Approach flow patterns with spillway axis skewed, Q = 10,000 cfs, skew angle = 10^0

Figure 15b. Approach flow patterns with spillway axis skewed, Q = 10,000 cfs, skew angle = 20^0

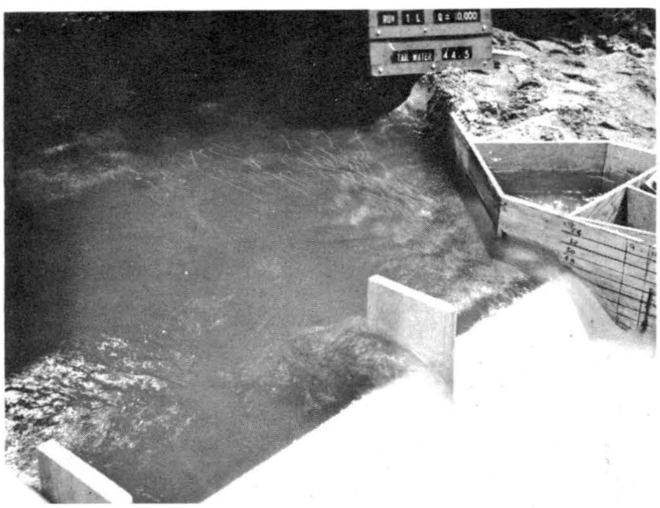


Figure 15c. Approach flow patterns with spillway axis skewed, Q = 10,000 cfs, skew angle = 30^0

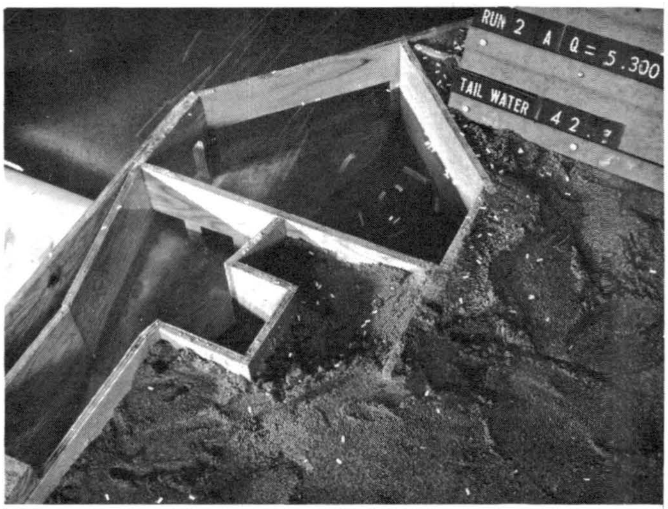


Figure 16. Surface streamlines entering collection gallery

centerline of the trap spillway terminating near the collection gallery gates and at the vertex of the present collection gallery.

The intakes of the appurtenant holding ponds are to be located in this gallery. With due consideration of the nature of fish migration and the location of the intakes in the collection gallery, it was decided that modification to the gallery was not required.

Water always entered the trap complex from the collection gallery through three open ports. The flow then passed through the converging section, dropped down the chute, and formed a hydraulic jump. The water surface downstream from the jump and in the vicinity of the trap was very undulatory.

At low tailwaters a "boil" was observed on the water surface in the right corner of the stilling basin between the ports leading to the spillway collection gallery and the river channel. The maximum height of the "boil" was about 0.5 ft. at a total discharge of 5,300 cfs and about 1.5 ft. at a total discharge of 15,400 cfs. At maximum tailwater the boil was not evident. At minimum or maximum tailwater the hydraulic performance of the stilling basin was satisfactory.

Some modification may be necessary to eliminate the boil if the movement of fish into the trap is hindered. However, the scope of this study did not include a study within the trap since a larger model would be required to fully study the modification.

The flow divided at the stilling basin. Part continued downstream through the port to the river channel. The rest was diverted to the right through a port leading to the spillway collection gallery.

The flow passed through the spillway collection gallery ports into the main flow on the spillway apron. The number of ports between the spillway collection gallery and the spillway apron was reduced when the apron was shortened. The performance of the reduced number of ports remained satisfactory.

The flow continuing downstream created two eddies near the outlet of the fish trap. One eddy was located near the wing wall at the left band and the other just to the right of the port near the training wall. The larger eddy located on the left could be detrimental from a fish trapping standpoint by providing a resting area where the fish could remain and, thus, would not follow the main current into the trap. Reduction or elimination of this eddy was required. The modifications of the wing wall and training wall are described in the following section.

Wing wall modification - Two wall arrangements were installed in the model and observed for different discharge conditions. In one modification the walls were parallel to the direction of flow. In the other the walls were flared at an angle of about 20^0 from the direction of flow.

The large eddy near the bank as previously noted was eliminated when the parallel walls were installed. Fig. 17 shows the paralled wall modification with a total discharge of 5,000 cfs passing through the model.

Figure 17. Fish trap outlet with parallel walls, Q= 5,000 cfs, tailwater elevation = 42.5

Conditions of operation of the model with the flared wall modification are shown in Fig. 18. The eddy near the left bank was not evident with the flared walls installed. Performance of the outlet with the flared wall arrangement was satisfactory.

Figure 18. Fish trap outlet with 20^0 flared walls, Q = 5,000 cfs, tailwater elevation = 42.5

Scour Control

Scour tests - Tests were performed to determine the location of probable scour in the sand channel downstream from the stilling basin. The tests were performed with discharges as great as 15,000 cfs with maximum and minimum tailwater conditions. All basins and end sills as previously discussed in the sections "Stilling Basin" and "End Sill" were tested.

Figure 19 shows scour downstream from the original basin for a discharge of 15,000 cfs and a tailwater elevation of 46.0. The maximum scour occurred approximately 15 ft. to 20 ft. downstream from the basin in this case.

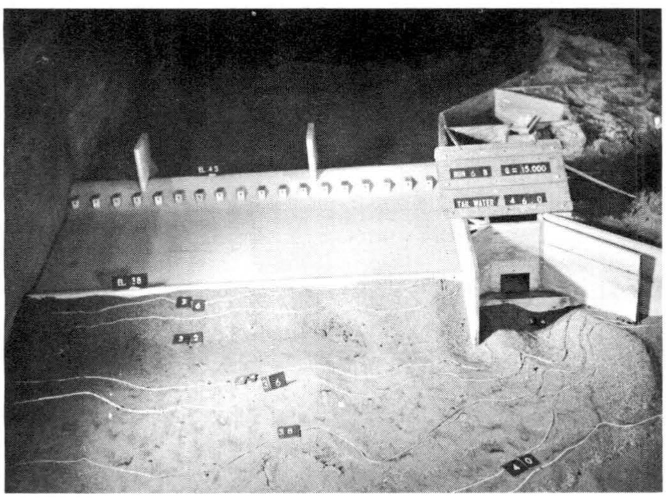


Figure 19. Scour downstream from original stilling basin, Q = 15,000 cfs, tailwater elevation = 46.0

Figs. 20 and 21 show scour downstream from the basins with apron lengths reduced 10 ft. and 12 ft., respectively, for a discharge of 15,000 cfs and tailwater elevation of 45.5. The solid end sill was installed in these cases. Maximum scour occurred at a distance of about 25 ft. to 30 ft. downstream from the end sill in each of these cases.

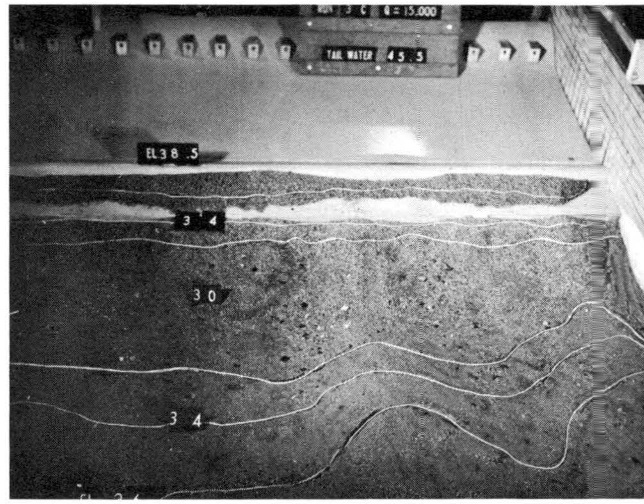


Figure 20. Scour downstream from stilling basin with apron length reduced 10 ft., Q = 15,000 cfs, tailwater elevation = 45.5

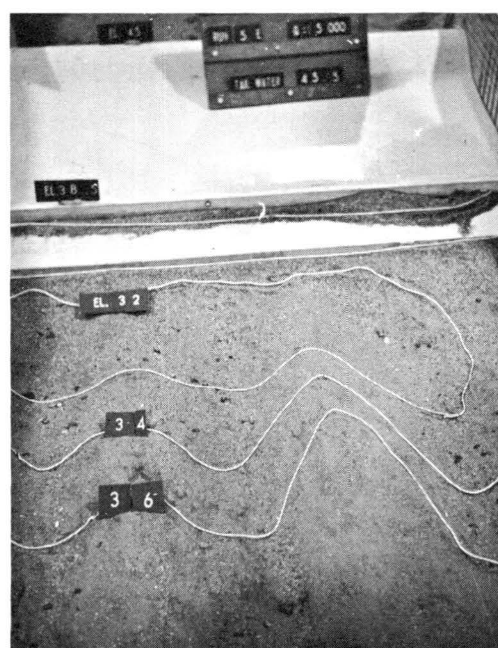


Figure 21. Scour downstream from stilling basin with apron length reduced 12 ft., Q = 15,000 cfs, tailwater elevation = 45.5

Tests were also performed with the dentated end sill #1 and #2 installed with the apron length reduced 12 ft. A layer of crushed gravel of about 3/16-in. median diameter (model dimensions) was placed over the sand bed channel for a distance of about 50 ft. downstream from the end sill. Results of the scour tests with the solid end sill and with dentated end sills #1 and #2 are shown in Figs. 22a, 22b and 22c, respectively. These tests were performed with the design discharge of 15,000 cfs and the minimum estimated tailwater of 45.5 for the design discharge. The maximum scour hole is located approximately 8 ft. to 12 ft. downstream from the solid sill, 6 ft. to 10 ft. downstream from dentated sill #1, and just downstream from dentated sill #2. From these scour tests, it was apparent that the performances of the solid end sill and the dentated end sill #1 were much better than dentated end sill #2.

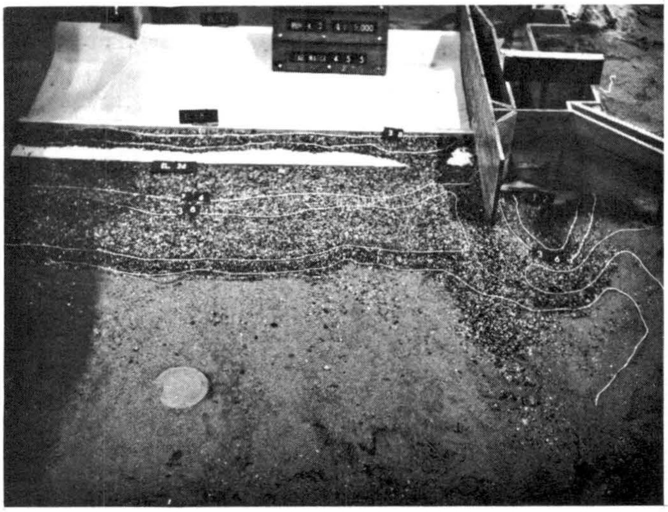


Figure 22a. Scour downstream from stilling basin with apron length reduced 12 ft. and solid end sill installed, Q = 15,000 cfs, tailwater elevation = 45.5

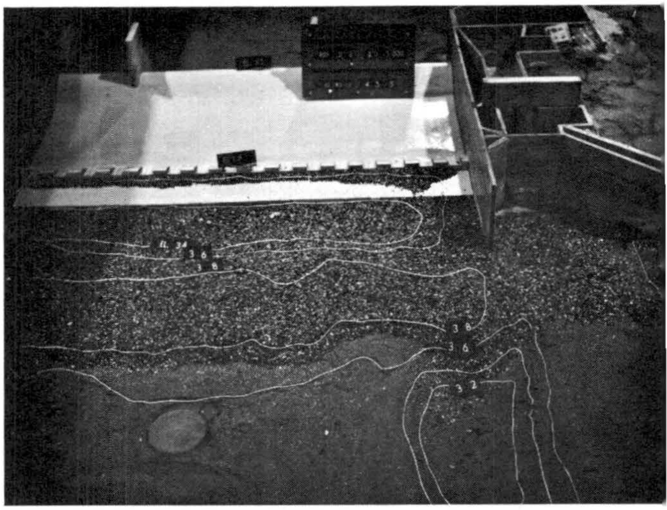


Figure 22b. Scour downstream from stilling basin with apron length reduced 12 ft. and dentated end sill #1 installed, Q = 15,000 cfs, tailwater elevation = 45.5

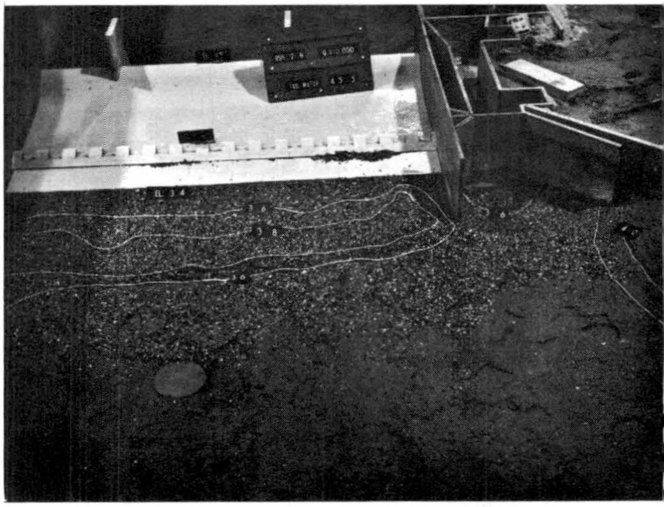


Figure 22c. Scour downstream from stilling basin with apron length reduced 12 ft. and dentated end sill #2 installed, Q = 15,000 cfs, tailwater elevation = 45.5

Riprap - Average velocities over the end sill of the spillway at different tailwater elevations are given in Table II. The maximum average velocity is about 10 fps for a minimum tailwater and a discharge of 18, 000 cfs. The maximum size of riprap required for a velocity of 10 fps is about a 15-in. diameter stone. This size of stone is based upon data developed by the Bureau of Reclamation.[2] It is suggested that the riprap be composed of a well graded mixture, but with most of the stones of the 15-in. diameter. Figure 23 gives a suggested gradation curve for the riprap blanket. The riprap should be placed in a layer at least 2 ft. thick over a gravel or reverse filter layer. It is suggested that this riprap blanket extend a distance of 50 ft. downstream from the end sill and should be used downstream from the fish trap in the transition to the river channel. The riprap should be placed on both the bed and banks of the river.

TABLE II. AVERAGE END SILL VELOCITIES

Discharge in cfs	Tailwater elevation in feet	Velocity over end sill in fps
5, 100	45. 0	3. 3
5, 100	42. 5	5. 4
10, 100	46. 5	5. 3
10, 100	44. 5	7. 1
15, 000	47. 0	7. 5
15, 000	45. 5	9. 0
18, 000	48. 2	7. 8
18, 000	46. 2	9. 9

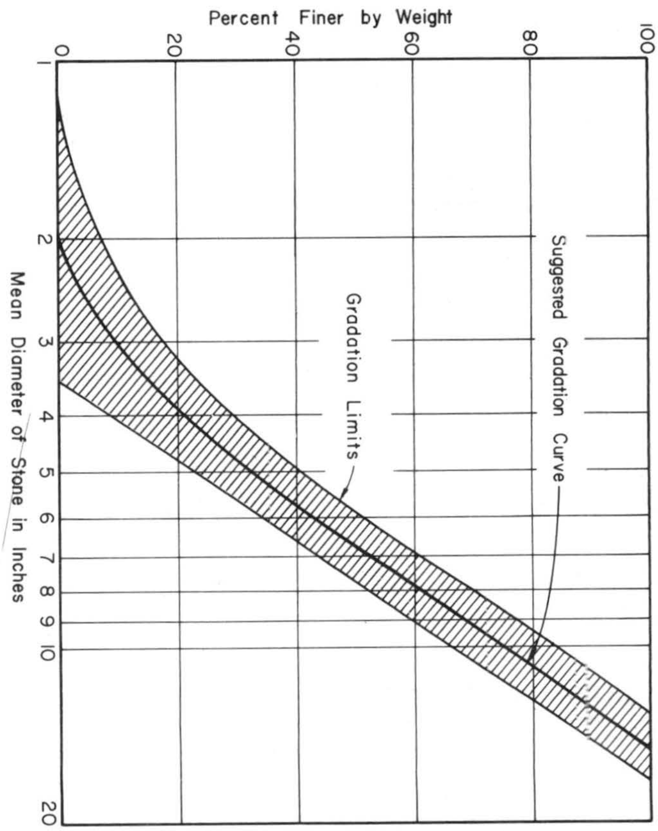


Figure 23. Riprap gradation curve

Screen Tests

The tests performed on the screens provided data necessary to determine the head loss across the screens relative to the velocity approaching the screen. The tests were performed with the longitudinal axis of the bars horizontal and tests were performed with the screens extending above the free water surface. The screens tested had bars located at center to center distance of 3/4 in., 1 in., 1 1/2 in. and 2 in. The frames were installed in the test section with the bottom pinned and the top capable of being rotated into the flow at angles of 0^0, 10^0, 20^0 and 30^0 measured from the vertical.

Measurements were made of the discharge and the head upstream and downstream from the screens at the locations shown in Fig. 6. These data are given in Appendix B. A current meter check of the approach velocity was also made.

During the tests, these screens were subjected to approach velocities from 1 fps to about 7 fps. At velocities greater than about 2. 5 fps for the 3/4-in. and 1-in. spacings and greater than 3 fps for the 1 1/2-in. and 2-in. spacings, the bars in the screens vibrated in a transverse direction and rotated about their longitudinal axis. The flexure of the bars caused by the vibration was such that the paint applied during the construction was completely removed from about the middle third of the length of most of the bars. The rotation produced an abrasive action which created a groove on the bars where the supporting frame was located. The vibrations were transmitted to the flume walls and considerable noise accompanied the tests.

[2] Peterka, A. J., Hydraulic Design of Stilling Basins and Energy Dissipators. Engineering Monograph No. 25, U. S. Bureau of Reclamation; revised July 1963, pp. 207-217.

Standing waves were observed in the test section for some of the tests. The standing waves were generally observed downstream from the screens. They were also observed upstream of the screens at near maximum and maximum discharges. Whenever standing waves occurred, measurements of the trough and crest of the waves were made and the average was used to determine the water surface elevation.

Loss coefficients - The head loss across the screen was determined using the energy equation written as:

$$z_1 + y_1 + \frac{V_1^2}{2g} - K\frac{V_1^2}{2g} = z_2 + y_2 + \frac{V_2^2}{2g}$$

in which:

- z is the elevation above the datum plane in ft.
- y is the water depth in ft.
- V is the velocity in fps
- g is the acceleration of gravity in ft/sec^2
- K is head loss coefficient

1 and 2 refer to locations upstream and downstream from the screens, respectively.

The head loss due to the channel boundary is included in the coefficient K but is very small in comparison with the head loss due to the screen and is assumed to be negligible for the distance between points of measurement of the water surface.

The head loss-approach velocity relationships for screens inclined into the flow at angles of 0^0, 10^0, 20^0 and 30^0 are presented graphically in Figs. 24, 25, 26 and 27, respectively. The loss coefficients determined from these curves are presented in Table III.

TABLE III. SCREEN LOSS COEFFICIENTS

Bar spacing center to center	Angle screen inclined from vertical	Loss coefficient K	K average
3/4"	0^0	5.29	
3/4"	10^0	5.20	5.29
3/4"	20^0	5.53	
3/4"	30^0	5.14	
1"	0^0	1.93	
1"	10^0	1.85	1.87
1"	20^0	1.91	
1"	30^0	1.77	
1-1/2"	0^0	0.66	
1-1/2"	10^0	0.70	0.72
1-1/2"	20^0	0.72	
1-1/2"	30^0	0.78	
2"	0^0	0.46	
2"	10^0	0.45	0.46
2"	20^0	0.45	
2"	30^0	0.46	

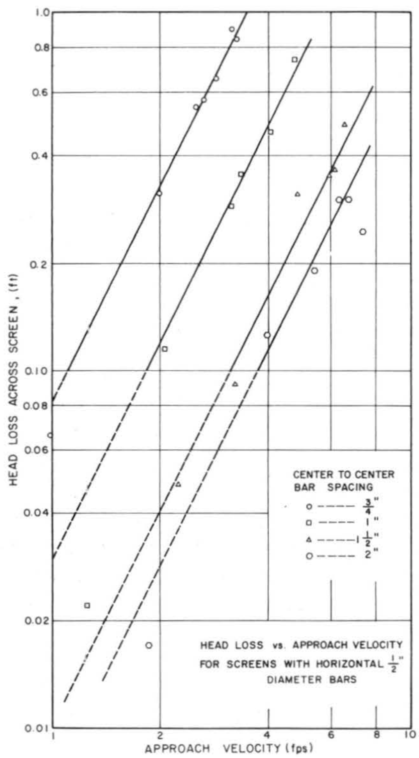


Figure 24. Head loss-approach velocity relationship for a vertical screen

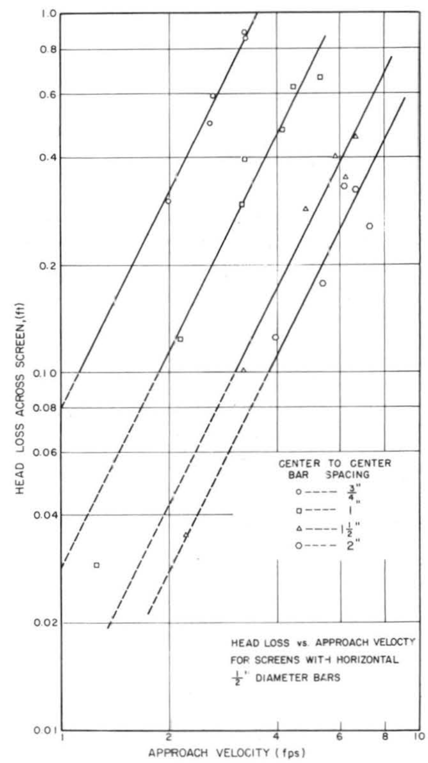


Figure 25. Head loss-approach velocity relationship for a screen inclined 10^0 from the vertical

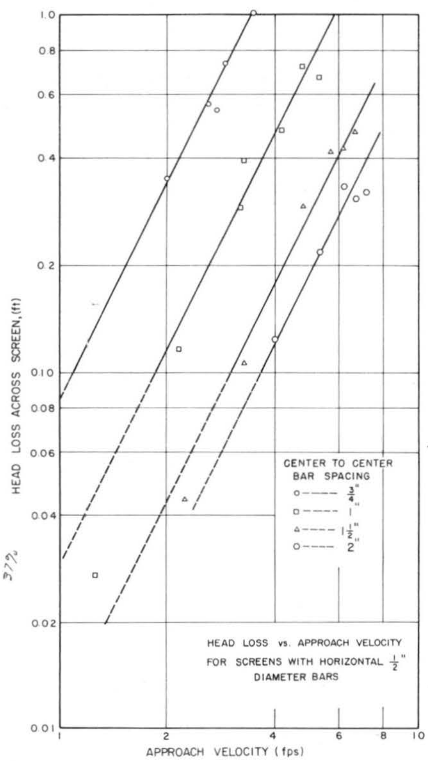


Figure 26. Head loss-approach velocity relationship for a screen inclined 20^0 from the vertical

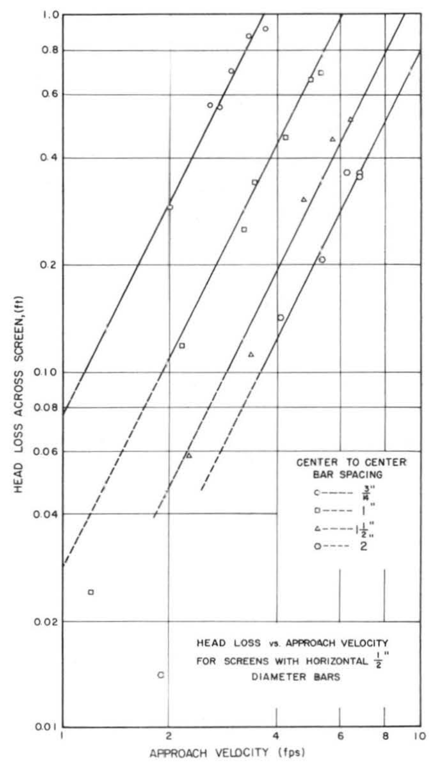


Figure 27. Head loss-approach velocity relationship for a screen inclined 30^0 from the vertical

Chapter IV

CONCLUSIONS AND RECOMMENDATIONS

Main Spillway

The performance of the model spillway indicated that the basic design of the spillway was satisfactory. Operation of the spillway was satisfactory for discharges as great as 26, 200 cfs.

Pressure measurements recorded at the piezometer taps indicated positive pressures at all locations for discharges less than about 16, 000 cfs. Negative pressures with a magnitude of -1.7 ft. of water were recorded at a discharge of 26, 200 cfs. These negative pressures were not cause for concern and the performance of the spillway was still considered to be satisfactory.

Modifications of the basic spillway were tested. The cost of construction of the prototype spillway would be reduced if the modified spillway performance was satisfactory. The modifications included removing the chute blocks, reducing the apron length, and replacing the solid end sill with a dentated end sill. The recommended spillway based upon results of this model study is shown in Fig. 28. The model spillway rating curve is given in Fig. 7.

Since the bridge may not be required for access to the traps, the piers may be eliminated in the prototype. If the piers are removed in the final design, the rating curve, as given in Fig. 7, will not be applicable if the crest length remains 153 ft. However, if the crest length were reduced 8 ft. (four piers 2 ft. wide), the curve of Fig. 7 would still give a close representation of the stage-discharge relationship.

Removal of the chute blocks caused the toe of the hydraulic jump to become more oscillatory at the minimum estimated tailwater elevation. This condition had little, if any, effect on the overall jump characteristics and could be beneficial in preventing fish from resting in the eddies created by the blocks at maximum tailwater elevations. Removal of the chute blocks is recommended.

Reduction in the length of the apron by a total of 12 ft. did not reduce the efficiency of the stilling basin when operated within the limits of the estimated tailwater rating curve. The hydraulic jump remained in the basin until the tailwater was lowered 1.7 ft. to 2.5 ft. below the minimum estimated tailwater elevation. A total reduction of 12 ft. in the length of the apron is recommended.

A total of three end sills were tested, one solid end sill and two dentated end sills. The three end sills performed satisfactorily in terms of containing the jump within the basin. The solid sill and dentated sill #1 operated best during the scour tests. They caused the maximum scour hole to form at a distance of 8 ft. to 10 ft. downstream from the end sill. The maximum scour hole occurred immediately downstream from dentated end sill #2. Therefore, either the solid end sill or dentated end sill #1 is recommended for use.

Dam axis skewed - Skewing the axis of the dam at angles of 10^0, 20^0 and 30^0 appeared to have little, if any, effect on the performance of the spillway. However, this was a qualitative observation and without more detailed testing at skewed angles of 20^0 and 30^0, a final conclusion cannot be reached. At a skew angle of 10^0, the spillway would perform almost identically as if the axis were normal to the flow. However, the piers should be oriented parallel to the flow. It is suggested that the dam be installed with the axis normal to the flow or at a maximum skew angle of 10^0. At angles greater than 10^0, more detailed tests should be performed to verify the spillway performance.

Scour Protection

Graded riprap with most of the stones having a diameter of 15 in. should be placed in a layer 2 ft. thick over a gravel or reverse filter layer. A riprap gradation curve is given in Fig. 23. This riprap blanket should extend a distance of 50 ft. downstream from the end sill. It should be placed on both the bed and banks and at the transition from the fish trap to the river channel.

Fish Trap

The fish trap exterior boundary performed satisfactorily for all discharges. The flow passed through the traps as required with streamlines outward from the channel collection gallery for all discharges.

A large eddy formed downstream from the trap near the channel bank. This eddy was undesirable for efficient trapping operations. It was eliminated by modifying the wingwalls. Details of this modification are given in Fig. 28.

In the interior of the trap the water surface was very undulatory. A "boil" was evident between the ports leading to the spillway collection gallery and to the river channel. No attempt was made with this model to modify the trap area to reduce or eliminate the undulating water surface. Modifications in the trap region should be studied at a larger scale.

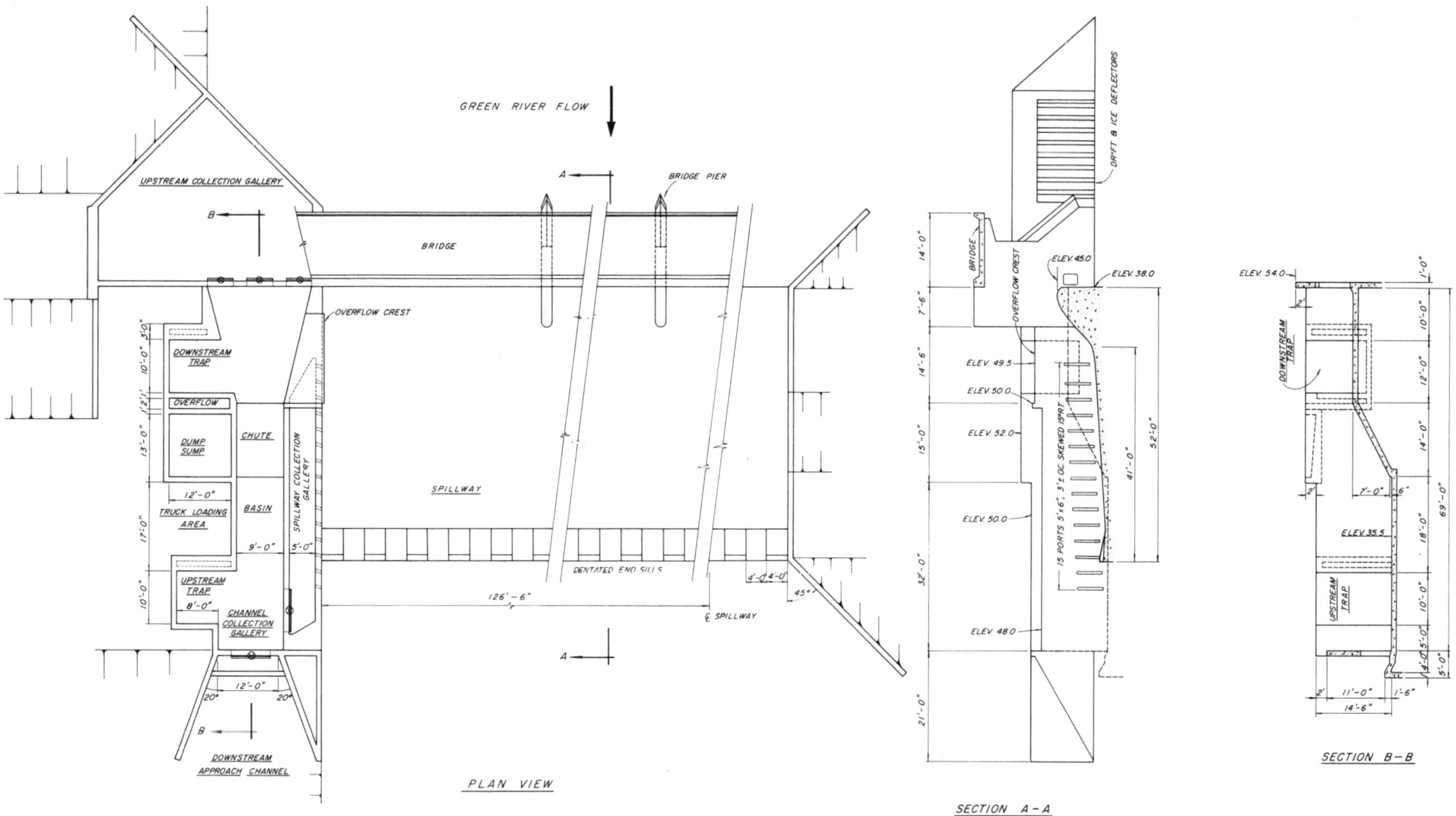


FIGURE 28 DETAILS OF THE RECOMMENDED SPILLWAY AND FISH TRAP

Screens

Loss coefficients - The head loss-approach velocity relationships for the screens are given in Figs. 24, 25, 26 and 27. Some scatter in the data is noted. This scatter is due in part to the vibration of the bars as previously described and in part due to the calculations based upon measurements of the water surface when standing waves were present. It was found that this head loss was quite sensitive to water depth.

The loss coefficients for the screens are presented in Table III. The coefficients were determined from the head loss-approach velocity relationship. When using the loss coefficients for design, it is suggested that the average loss coefficient for any particular bar spacing be used for any inclination of the screen within the limits of the tests. These coefficients are for clean screens only and cannot account for loss of flow area caused by trash accumulation.

During the testing of the screens considerable vibration of the bars was observed. Therefore, it is suggested that the bar be rigidly supported in the prototype. This rigid support will result in reduced maintenance of the screen bars which might result from fatigue and wear.

APPENDIX A

SPILLWAY PRESSURE HEADS

TABLE A-1

PRESSURE HEADS ON SPILLWAY CREST AND APRON WITH FISH TRAP GATES CLOSED

Run Number	1	2	3	4	5	6	7	8	9	10
Total Discharge cfs	5, 100	5, 100	6, 000	6, 000	8, 200	8, 200	10, 000	10, 000	12, 200	12, 200
Head Water Elevation in ft.	48.0	48.0	48.5	48.5	49.2	49.2	49.7	49.7	50.3	50.3
Tail Water Elevation in ft.	44.5	42.7	45.0	43.0	45.8	44.3	46.4	44.5	47.2	44.7
Piezometer Number	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. cf water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water
A 1	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
3	1.3	1.3	1.3	1.5	1.3	1.3	1.0	1.0	0.5	0.5
4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	0.7	0.7	0.7	0.7	1.3	1.0	1.0	1.0	1.0	1.0
6	1.0	1.0	1.3	1.0	1.7	1.3	1.5	1.5	1.7	1.7
7	1.5	1.0	2.0	1.0	2.0	1.3	2.2	1.3	2.5	1.5
8	2.5	1.3	3.3	1.3	3.3	1.7	3.5	1.7	3.5	2.3
9	5.7	3.7	6.7	3.7	7.2	4.9	7.5	5.5	7.7	6.2
10	6.3	3.8	7.3	3.8	7.6	5.0	8.0	4.6	8.8	5.6
11	6.0	4.0	7.0	4.0	7.0	4.5	7.2	4.0	7.5	2.8
12	7.0	5.3	7.7	5.5	8.0	6.0	8.3	6.0	8.5	5.0
13	7.5	6.0	8.5	6.2	8.8	7.0	8.8	7.2	9.2	6.8
14	8.0	6.5	9.0	7.0	10.3	8.3	10.3	8.5	10.7	8.7
15	9.0	7.2	9.7	7.8	10.2	8.8	11.0	9.0	11.5	9.5
B 1	2.7	2.7	2.7	2.7	2.7	2.7	2.4	2.4	2.2	2.4
2	2.1	2.1	2.1	2.1	2.6	2.6	2.6	2.4	2.6	2.6
3	1.5	1.5	1.5	1.5	1.3	1.3	1.3	1.0	1.0	1.0
4	0.5	0.8	0.8	1.0	0.5	0.5	0.5	0.5	0.5	0.5
5	0.7	1.0	1.0	1.0	1.0	1.0	1.3	1.0	1.3	1.0
6	0.5	0.5	1.0	0.7	1.0	0.7	1.3	1.0	1.5	1.0
7	1.0	0.7	1.5	1.0	1.7	1.0	2.0	1.3	2.5	1.3
8	2.0	1.3	3.0	1.5	3.2	1.7	3.3	2.0	3.7	2.3
9	5.7	3.5	6.7	3.7	6.9	4.7	7.2	4.9	7.5	5.9
10	6.3	3.8	7.3	3.8	7.8	5.3	8.0	5.3	8.6	5.3
11	6.2	4.0	7.0	4.0	7.0	4.8	7.2	4.5	7.5	3.2
12	7.0	5.0	7.7	5.3	7.7	6.0	8.0	6.0	8.5	5.0
13	7.5	6.0	8.2	6.0	8.5	7.0	8.8	7.0	9.2	6.5
14	8.0	6.7	9.0	6.7	9.3	7.7	9.5	8.0	10.0	7.3
15	9.0	7.2	9.7	7.5	10.3	8.5	10.8	9.0	12.2	8.8

TABLE A-1 - Continued

PRESSURE HEADS ON SPILLWAY CREST AND APRON WITH FISH TRAP GATES CLOSED

Run Number	11	12	13	14	15	16	17	18	19	20
Total Discharge cfs	14,000	14,000	15,800	15,800	18,000	18,000	20,000	20,000	26,200	26,200
Head Water Elevation in ft.	50.8	50.8	51.3	51.3	51.7	51.7	52.0	52.0	53.0	53.0
Tail Water Elevation in ft.	45.8	47.3	47.6	45.3	48.2	46.2	46.5	48.8	49.3	46.5
Piezometer Number	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water
A 1	2.2	2.2	2.2	2.2	1.7	1.7	1.5	1.7	1.7	1.7
2	1.6	1.6	1.6	1.6	1.1	1.1	0.9	1.1	1.1	1.1
3	0.0	0.3	0.2	0.0	-0.5	-0.5	-1.0	-0.7	-1.0	-1.7
4	0.8	0.8	1.0	0.8	-0.5	0.5	0.2	0.8	0.5	-0.2
5	0.8	0.8	1.0	0.8	0.7	0.7	0.7	0.7	1.0	0.7
6	1.8	2.0	2.5	2.0	2.5	2.0	2.0	3.3	3.5	2.7
7	1.8	2.7	3.3	2.3	3.7	2.5	2.5	4.5	4.5	3.5
8	2.5	4.0	4.5	3.0	5.0	3.5	3.7	6.0	6.0	4.5
9	6.7	8.2	8.5	7.2	9.2	7.7	8.2	9.9	10.2	9.2
10	6.6	9.3	9.8	7.1	10.6	8.0	8.3	11.3	11.8	9.8
11	3.5	8.0	8.8	4.0	9.2	4.5	5.0	10.2	10.5	6.0
12	6.0	8.7	9.5	3.5	9.7	6.0	6.5	10.7	11.0	4.7
13	7.5	10.5	11.0	8.3	11.2	9.0	9.2	12.0	12.8	9.2
14	9.3	11.0	11.5	8.8	11.7	9.5	10.0	12.5	13.3	9.7
15	10.5	12.0	12.2	10.0	13.0	11.0	11.5	13.8	13.8	11.2
B 1	2.0	2.0	1.2	1.4	1.4	1.4	1.4	1.0	0.7	0.4
2	2.4	2.4	2.1	2.1	2.1	2.3	2.4	2.1	2.1	[illegible]
3	0.7	0.7	0.5	0.5	0.0	0.0	0.0	-0.3	-0.7	-1.3
4	0.2	0.3	0.0	0.0	-0.2	-0.5	-0.5	-0.2	-0.5	-1.2
5	1.2	1.3	1.3	1.0	1.3	1.0	1.0	1.5	1.3	[illegible]
6	1.3	1.7	2.0	1.5	2.0	1.5	1.5	2.5	2.5	1.7
7	1.8	2.7	3.0	2.0	3.5	2.3	2.5	4.0	4.5	3.3
8	2.5	4.0	4.3	2.7	4.7	3.3	3.5	5.5	5.7	4.3
9	6.2	7.7	8.2	6.5	8.7	7.2	7.7	9.2	9.9	8.7
10	6.1	8.8	9.6	6.6	10.0	7.3	7.8	10.8	11.3	9.3
11	3.5	7.8	8.2	3.0	8.8	4.0	4.8	9.8	10.0	5.7
12	5.0	8.7	9.3	4.5	9.7	6.3	6.7	10.5	10.7	5.5
13	7.0	9.7	10.2	5.8	10.8	7.5	8.0	11.2	11.8	7.5
14	9.8	10.5	11.0	6.7	11.5	8.3	8.7	12.0	12.7	8.5
15	9.8	12.0	12.5	8.8	13.0	10.2	11.0	13.8	14.8	11.2

TABLE A-2

PRESSURE HEADS ON SPILLWAY CREST AND APRON WITH FISH TRAP GATES OPEN

Run Number	1A	2A	3A	4A	5A	6A	7A	8A
Total Discharge cfs	5,300	5,300	8,200	8,200	12,300	12,300	15,400	15,400
Head Water Elevation in ft.	48.0	48.0	49.0	49.0	50.3	50.3	50.8	50.8
Tail Water Elevation in ft.	44.7	42.7	46.0	44.0	47.0	45.0	47.8	45.7
Piezometer Number	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water	Pressure Head ft. of water
A 1	2.7	2.7	2.7	2.7	2.4	2.7	-	-
2	2.1	2.1	2.1	2.1	1.8	2.1	-	-
3	1.5	1.5	1.5	1.5	0.7	0.7	0.5	0.5
4	1.2	1.0	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	1.0	0.7	1.7	1.5	2.5	1.7	2.7	2.0
7	1.3	1.0	2.0	1.3	3.0	1.7	-	-
8	2.5	1.3	3.7	2.0	4.5	2.5	-	-
9	5.7	2.9	6.9	4.9	8.2	6.2	8.9	6.9
10	6.3	2.8	7.6	5.3	9.3	5.8	10.0	7.3
11	6.5	3.5	7.5	5.0	8.2	4.5	9.2	6.0
12	7.3	5.0	8.3	6.0	9.0	6.5	9.7	7.5
13	8.2	6.0	9.5	7.5	10.5	8.5	-	-
14	8.7	6.5	10.0	8.0	11.0	9.0	11.7	9.5
15	9.2	7.2	10.5	8.8	11.8	9.8	12.5	10.5
B 1	2.7	2.7	2.7	2.7	2.4	2.2	2.2	2.2
2	2.1	2.1	2.6	2.6	2.8	2.6	2.8	2.6
3	1.5	1.5	1.5	1.7	1.0	1.0	1.0	1.0
4	1.2	1.0	-	-	-	-	-	-
5	1.0	1.3	-	-	-	-	-	-
6	0.7	0.7	1.3	1.0	2.5	2.0	-	-
7	1.3	1.0	2.0	1.3	3.0	1.7	-	-
8	2.5	1.5	4.3	2.7	5.0	3.3	-	-
9	5.7	3.2	6.9	4.9	7.9	6.2	8.5	6.7
10	6.6	3.3	7.6	5.3	9.0	5.8	9.8	7.0
11	6.5	3.8	7.5	5.0	8.0	5.0	9.0	5.8
12	7.3	4.7	8.0	6.0	9.0	6.7	10.0	7.7
13	6.8	5.5	8.8	7.0	9.8	7.5	10.5	8.2
14	8.5	6.0	9.5	7.7	10.5	8.0	11.0	8.7
15	9.2	6.8	10.5	8.8	11.5	9.5	12.3	10.5

APPENDIX B

SCREEN LOSS DATA

TABLE B-1

SCREEN LOSS DATA FOR SCREENS WITH BARS ON 3/4-IN. CENTER TO CENTER SPACING

Run Number	Upstream Head	Downstream Head	Discharge	Approach Velocity	Angle Screen Inclined from Vertical	Run Number	Upstream Head	Downstream Head	Discharge	Approach Velocity	Angle Screen Inclined from Vertical
	ft.	ft.	cfs	fps			ft.	ft.	cfs	fps	
A-1	3.688	1.022	24.15	3.27	0^0	B-1	1.901	0.585	9.92	2.60	10^0
A-2	3.150	0.990	20.12	3.19	0^0	B-2	3.677	1.024	23.98	3.26	10^0
A-3	2.580	0.774	14.82	2.87	0^0	B-3	3.112	1.006	20.12	3.23	10^0
A-4	2.021	0.587	10.15	2.51	0^0	B-4	2.605	0.784	15.15	2.91	10^0
H-A-1	3.418	2.792	18.10	2.65	0^0	H-B-1	3.424	2.770	18.10	2.64	10^0
H-A-2	3.123	2.794	12.38	1.98	0^0	H-B-2	3.122	2.807	12.38	1.98	10^0
H-A-3	2.896	2.829	5.72	0.99	0^0	H-B-3	2.897	2.835	5.72	0.99	10^0
C-1	2.584	0.794	14.93	2.89	20^0	D-1	1.84	0.594	9.41	2.56	30^0
C-2	3.823	1.165	26.59	3.48	20^0	D-2	3.487	1.203	25.69	3.69	30^0
C-3	3.100	1.001	19.88	3.205	20^0	D-3	3.021	1.016	19.88	3.29	30^0
C-4	1.88	0.602	9.67	2.575	20^0	D-4	2.485	0.794	14.60	2.94	30^0
H-C-1	3.400	2.80	18.55	2.73	20^0	H-D-1	3.400	2.80	18.55	2.73	30^0
H-C-2	3.114	2.75	12.31	1.98	20^0	H-D-2	3.110	2.809	12.31	1.98	30^0
H-C-3	2.906	2.847	5.72	0.98	20^0	H-D-3	2.909	2.847	5.72	0.98	30^0

Note: Slope of flume set at 0.0179 for all runs A, B, C and D. For runs H-A, H-B, H-C and H-D, flume was horizontal.

TABLE B-2

SCREEN LOSS DATA FOR SCREENS WITH BARS ON 1-IN. CENTER TO CENTER SPACING

Run Number	Upstream Head	Downstream Head	Discharge	Approach Velocity	Angle Screen Inclined from Vertical	Run Number	Upstream Head	Downstream Head	Discharge	Approach Velocity	Angle Screen Inclined from Vertical
	ft.	ft.	cfs	fps			ft.	ft.	cfs	fps	
						B-1	1.550	0.706	10.08	3.25	10^0
A-2	3.191	1.430	30.30	4.75	0^0	B-2	3.635	1.650	38.40	5.28	10^0
A-3	2.433	1.074	19.84	4.08	0^0	B-3	3.390	1.278	30.30	4.47	10^0
A-4	1.60	0.723	10.62	3.32	0^0	B-4	2.455	1.078	20.00	4.07	10^0
H-A-1	3.147	2.821	19.92	3.16	0^0	H-B-1	3.138	2.800	19.92	3.17	10^0
H-A-2	2.918	2.796	12.03	2.06	0^0	H-B-2	2.914	2.788	12.45	2.14	10^0
H-A-3	2.816	2.794	7.03	1.25	0^0	H-B-3	2.815	2.786	7.03	1.25	10^0
C-1	1.550	0.703	10.08	3.25	20^0	D-1	1.550	0.704	10.54	3.41	30^0
C-2	3.630	1.650	38.40	5.29	20^0	D-2	3.649	1.650	38.40	5.26	30^0
C-3	3.218	1.410	30.30	4.71	20^0	D-3	3.115	1.430	30.50	4.90	30^0
C-4	2.394	1.084	19.72	4.12	20^0	D-4	2.336	1.095	19.60	4.19	30^0
H-C-1	3.129	2.800	19.92	3.18	20^0	H-D-1	3.125	2.844	19.92	3.19	30^0
H-C-2	2.907	2.784	12.45	2.14	20^0	H-D-2	2.914	2.784	12.45	2.14	30^0
H-C-3	2.813	2.786	7.03	1.25	20^0	H-D-3	2.810	2.786	6.65	1.18	30^0

Note: Slope of flume set at 0.0179 for all runs A, B, C and D. For runs H-A, H-B, H-C and H-D, flume was horizontal.

TABLE B-3

SCREEN LOSS DATA FOR SCREENS WITH BARS ON $1\frac{1}{2}$-IN. CENTER TO CENTER SPACING

Run Number	Upstream Head	Downstream Head	Discharge	Approach Velocity	Angle Screen Inclined from Vertical	Run Number	Upstream Head	Downstream Head	Discharge	Approach Velocity	Angle Screen Inclined from Vertical
	ft.	ft.	cfs	fps			ft.	ft.	cfs	fps	
A-1	4.064	2.084	52.92	6.50	0^0	B-1	2.100	1.138	20.10	4.79	10^0
A-2	3.402	1.73	41.50	6.11	0^0	B-2	4.000	2.10	53.15	6.65	10^0
A-3	2.559	1.47	30.20	5.90	0^0	B-3	3.260	1.73	40.50	6.22	10^0
A-4	2.092	1.171	20.10	4.81	0^0	B-4	2.640	1.47	30.20	5.72	10^0
H-A-1	2.745	2.735	6.77	1.23	0^0	H-B-1	2.745	2.741	6.77	1.23	10^0
H-A-2	2.639	2.588	11.75	2.23	0^0	H-B-2	2.643	2.605	11.75	2.22	10^0
H-A-3	2.829	2.725	18.19	3.22	0^0	H-B-3	2.825	2.710	18.19	3.22	10^0
C-1	2.64	1.470	30.00	5.680	20^0	D-1	2.109	1.126	19.86	4.70	30^0
C-2	3.85	2.080	51.15	6.64	20^0	D-2	3.90	2.00	49.52	6.35	30^0
C-3	3.265	1.750	40.10	6.14	20^0	D-3	3.32	1.77	40.38	6.08	30^0
C-4	2.128	1.189	20.74	4.77	20^0	D-4	2.68	1.47	30.05	5.68	30^0
H-C-1	2.744	2.740	6.77	1.23	20^0	H-D-1	2.744	2.740	6.77	1.23	30^0
H-C-2	2.643	2.595	11.75	2.22	20^0	H-D-2	2.638	2.576	11.75	2.23	30^0
H-C-3	2.810	2.690	18.19	3.24	20^0	H-D-3	2.810	2.683	18.64	3.32	30^0

Note: Slope of flume set at 0.0179 for all runs A, B, C and D. For runs H-A, H-B, H-C and H-D, flume was horizontal.

TABLE B-4

SCREEN LOSS DATA FOR SCREENS WITH BARS ON 2-IN. CENTER TO CENTER SPACING

Run Number	Upstream Head	Downstream Head	Discharge	Approach Velocity	Angle Screen Inclined from Vertical	Run Number	Upstream Head	Downstream Head	Discharge	Approach Velocity	Angle Screen Inclined from Vertical
	ft.	ft.	cfs	fps			ft.	ft.	cfs	fps	
A-1	3.700	2.100	53.70	7.26	0^0	B-1	3.700	2.100	53.40	7.21	10^0
A-2	3.000	1.800	40.50	6.73	0^0	B-2	3.050	1.800	40.30	6.62	10^0
A-3	2.400	1.500	30.10	6.27	0^0	B-3	2.400	1.500	29.70	6.18	10^0
A-4	1.830	1.150	19.38	5.29	0^0	B-4	1.800	1.150	19.38	5.38	10^0
H-A-1	2.955	2.800	23.42	3.96	0^0	H-B-1	2.952	2.800	23.42	3.97	10^0
H-A-2	2.744	2.726	10.23	1.86	0^0	H-B-2	0.757	0.747	10.47	1.90	10^0
C-1	3.730	2.110	53.00	7.12	20^0	D-1	3.600	1.950	48.00	6.67	30^0
C-2	3.050	1.790	40.50	6.63	20^0	D-2	3.03	1.82	40.30	6.65	30^0
C-3	2.400	1.500	29.70	6.18	20^0	D-3	2.400	1.530	29.70	6.18	30^0
C-4	1.850	1.170	19.54	5.28	20^0	D-4	1.850	1.164	19.54	5.28	30^0
H-C-1	2.951	2.80	23.42	3.97	20^0	H-D-1	2.922	2.750	23.42	4.02	30^0
H-C-2	2.757	2.747	10.47	1.90	20^0	H-D-2	2.763	2.747	10.47	1.89	30^0

Note: Slope of flume set at 0.0179 for all runs A, B, C and D. For runs H-A, A-B, H-C and H-D, flume was horizontal.